

1 **TITLE**

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3 **Linearly Scalable Geothermic Fuel Cells**

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6 **CROSS REFERENCE APPLICATIONS**

7 This application is a continuation-in-part of utility
8 application no.10/053,207 filed on January 15, 2002 which
9 issued as U.S. Patent No. _____ on _____.
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11

12 **FIELD OF INVENTION**

13 The present invention relates to stacking fuel cells in
14 variable densities thereby forming conduction heaters to
15 heat resource layers for in situ mining of fluids including
16 oil and gas.
17

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19 **BACKGROUND OF THE INVENTION**

20 In situ mining of fluids by heating the resource layer
21 of a geologic formation was done extensively by Sweden in
22 World War II to acquire oil during a shortage. Electrical
23 resistance heaters were placed in boreholes often in
24 hexagonal patterns to surround a vapor borehole. The
25 resource layer is heated successively by applying current to
26 several rows of heating elements at a time. As soon as the
gas is removed from a section corresponding to a row of
heating resistors, the current is applied to the next row.

1 During wartime, the energy efficiency was not an issue,
2 since embedded shale could be made to produce oil by means
3 of available hydroelectric power.

4 Modern fuel cells are used downhole, but the purpose of
5 these fuel cells is to produce electricity for pump
6 operations. In the prior art, fuel cell stacks were
7 constructed in discreet modules of a size tailored to their
8 electrical demand or dictated by the compressive and other
9 forces at work inside the stack.

10 These short stacks were then typically connected in
11 arrays, which in aggregate produce the desired quantity of
12 electrical energy.

13 U.S. Pat. Application Publication No.US2002/0011
14 335A1(2002) to Zhang et al. discloses the use of downhole
15 fuel cells to generate electricity for mining operations.
16 Zhang at paragraph 0065, mentions the use of heat generated
17 by the fuel cell to power devices, which presumably could
18 include a hot water heater, and an unspecified use in highly
19 viscous, cool environments. There are no known teachings of
20 specifically designing a fuel cell assembly to heat a
21 resource layer in an in situ mining operation.

22 There is a need for a subterranean heater with greater
23 efficiency in terms of net energy production and reduced
24 energy cost for mineral extraction and other applications.
25 The heater would preferably consume a gaseous fuel of the

1 type generated by the subterranean formation being heated as
2 a normal by-product of the operation being performed to
3 avoid the need to import fuel.

4 Ideally, the heater would produce heat uniformly along
5 its length, without risk of autocombustion and would heat a
6 formation at a reduced net cost for fuel. The present
7 invention incorporates all of these advantages.

8

9 U.S. Patent Pub. No. 2002/0011335 (Zhang) teaches the
10 operation of down-hole fuel cells from down-hole "fuel and
11 oxidant vessels", page 2, ¶ 0038, (see Zhang, Fig. 1, #12 &
12 #14) also called "oxidant reservoirs" and "fuel
13 reservoirs" page 7, ¶ 0083. According to Zhang, when said
14 reservoirs "have exhausted their resources", they are
15 replenished from "external sources" like "bottles/tanks",
16 which are themselves types of reservoirs.

17 The present invention is unique, in part, in that the
18 fuel cells, located in a borehole, are in physical
19 communication with the planet surface through conduits.
20 Said conduits serve as continuous passages for the movement
21 of fluids-fuels, oxidants, and exhaust products--to and from
22 the fuel cells.

23 The present invention is an improvement because fuel
24 and oxidant can be supplied to the fuel cells continuously

1 from the surface without the need to replenish down-hole
2 reservoirs.

3 Geothermic Fuel Cells (GFC's) are unique in that
4 they are designed to be linearly scalable. This is to say
5 that GFC stacks are designed to be extensible, up to lengths
6 of 1000 feet. This has been achieved by designing a fuel
7 cell stack comprised of modular building blocks - modules
8 that can be assembled end-to-end to create stacks of
9 scalable length.

10

11 **SUMMARY OF THE INVENTION**

12 The operation of a fuel cell is well known in the art.
13 Generally, a fuel cell converts fuel and oxygen to heat and
14 electricity through an electrochemical reaction involving a
15 cathode, anode, and an electrolyte. In many typical
16 applications, fuel cells are used to generate electricity,
17 and heat is a waste product. Candidate fuel cells of the
18 planar solid oxide type are described in US patents
19 6,296,963 and 5,993,986.

20 In the present invention, the cells are used to
21 generate heat with electricity as a co-product. Part of the
22 heat maintains the fuel cell at operating temperature, while
23 the majority is transferred to the surrounding formation,
24 raising its temperature. The electricity produced by the
25 cells is conducted to the surface for use or sale/export.

1 Different applications of the heater and different
2 formations being heated will have different thermal output
3 requirements. Three general approaches to adapting the
4 output of the heater are anticipated. The first is by
5 altering the surface area of the individual fuel cells.
6 Smaller cells will produce less heat, while larger cells
7 produce more. Selecting different sizes when assembling the
8 heater will result in different thermal output. A second
9 approach is to introduce spacers between individual fuel
10 cells or small groups of fuel cells. This results in
11 lowered average output measured over a length of the heater
12 having both fuel cells and spacers, since the spacers
13 contribute no heat. A third approach is to stack
14 standardized fuel cell modules into a chosen density to get
15 a desired heat output.

16 In the preferred embodiment, some number of fuel cells
17 will be assembled into a heater segment, in a workshop or
18 factory environment. These segments will then be
19 transported to the site where the heater is to be installed.
20 The segments will be joined together to form the complete
21 heater. Preferably a heat exchanger will link the fuel cell
22 modules to the surface operations.

23 The present invention is a subterranean heater composed
24 of fuel cells. In the preferred embodiment, the apparatus
25 comprises a plurality of fuel cells assembled in a vertical

1 stack via plates generally referred to in the art as
2 "interconnect plates", or "bipolar plates". Conduits
3 throughout the stack supply the cells with fuel and air or
4 other oxidant, and remove exhaust gases. Preferably, the
5 fuel cell stack is enclosed in a casing adapted for
6 insertion into a well bore. An electrical connection is
7 provided to the far end (typically bottom) of the stack to
8 allow completion of an electric circuit.

9 The encased fuel cell stack is inserted into a
10 wellbore, preferably vertically, but potentially
11 horizontally or at some other orientation. Preferably, the
12 encased stack is cemented into the borehole by a suitably
13 heat conducting grout. Fuel and air are pumped into the
14 stack through the incorporated conduits to the fuel cells.
15 Within the fuel cells, electrochemical reactions take place
16 to produce electricity and heat. The electricity passes out
17 of the stack through an electric circuit. Fuel cells, of
18 the solid oxide type, which are preferred, operate at
19 temperatures in the 800 to 1000 degree Centigrade range.
20 This is also the preferred temperature range for many
21 subterranean heating applications. Heat passes from the
22 fuel cell stack to the underground formation by thermal
23 conduction. Thus, the operating fuel cell stack acts as a
24 down-hole conduction heater of enormous magnitude, perhaps

1 taking a year of operation to prepare a resource layer for
2 in situ mining.

3 In the preferred embodiment of the invention, conduits
4 for air, gaseous fuel, and exhaust are formed by aligning
5 holes in the interconnect plates. Communication for
6 circulation of these gases is provided by channels formed in
7 the surface of the interconnect plates.

8 The size and activity of the fuel cells themselves can
9 be modified to tailor the output of the thermal energy to
10 the formation being developed. Alternatively, the fuel
11 cells themselves may be standardized, to maximize production
12 efficiency, while the thermal properties of the stack are
13 varied by the insertion of spacers between active fuel
14 cells. Ideally, standardized fuel cell assemblies are
15 stacked to a desired density to adequately heat a particular
16 resource layer.

17 A refinement of the invention may be to include a heat
18 exchanger connecting the fuel cell stack to the surface.
19 The heat exchanger may be insulated to minimize heating of
20 overburden above the resource deposit. Further, the heat
21 exchanger may serve as a heat exchanger between the exhaust
22 gases leaving the fuel cell stack and the incoming streams
23 of fuel and/or air. By this method, the maximum amount of
24 thermal energy is retained within the target formation.

1 When the invention is used to produce hydrocarbonaceous
2 resources, it is intended that the volatile gases, produced
3 as the result of heating such deposits, should be used as
4 fuel to power the fuel cells. By this method, the fuel
5 cells will be self sustaining. Since the thermal process
6 produces a fuel stream, and the fuel is first converted to
7 electricity in the fuel cells, the production cycle is,
8 therefore, being powered by that fraction of total energy
9 that is otherwise usually wasted. The net result is an
10 increase in the overall thermodynamic efficiency of the
11 resource extraction system.

12 The fuel cell heater does double duty as both a heating
13 element and a power generator, resulting in increased
14 economic efficiency. The present invention overcomes many
15 of the diseconomies of other subterranean heaters by
16 reducing the cost of heat produced by the fuel cells.
17 Although the fuel cells do require fuel, the cost of fuel is
18 at least partially offset by the value of the electricity
19 the cells produce.

20 The present invention combines the advantages of down-
21 hole combustion heaters with the advantages of electrical
22 resistance heaters, while eliminating most of the
23 disadvantages typical of subterranean heaters of the prior
24 art. The present invention converts fuel to heat, like
25 combustion heaters, avoiding the inefficiencies of

1 electrical resistance heaters. The present invention
2 produces heat uniformly over the length of the heater, like
3 electrical resistance heaters, while avoiding the hot spots
4 and uneven heating of combustion heaters. The present
5 invention also eliminates the problems associated with
6 mixing fuel and air in flameless combustor heaters by
7 maintaining separation of these gases across the fuel cell
8 electrolyte.

9 Like the prior art Geothermal Fuel Cells (GFC's) are
10 also constructed in modules. Unlike the prior art, however,
11 GFC modules are assembled end-to-end, by means of mating
12 hardware and joined into "sticks" of multiple modules.
13 Preferably GFC modules measure 5 feet from coupling to
14 coupling, and each generates just over a kilowatt of
15 electrical power and produces around 3700 BTU of thermal
16 energy per hour. The "sticks" are 30 to 60 feet in length
17 and comprise 6-12 modules. The sticks are assembled in the
18 factory and are sealed for shipment to the field. The
19 sticks are then installed into vertical boreholes by
20 standard oil and gas drilling equipment. Sticks are joined
21 together to form "strings". These strings of GFC modules
22 can be up to 1000 feet in length. This enables GFC's to be
23 assembled in lengths that match the thickness of the
24 resource formations being heated, even if the formations are
25 very thick. Oil shale deposits in the Piceance Creek Basin

1 of Western Colorado for example are two thousand feet thick.
2 Of course, shorter GFC strings can be used to heat thinner
3 formations.

4 There are many design features unique to GFC's that
5 enable them to be scaled linearly so that the stacks can be
6 made as long as desired. For example, perforations in the
7 interconnect plates which form conduits for the transport of
8 fuel and air into the fuel cell stack are a common feature
9 of the prior art. (see Fig. 1A, US Patent No. 6,344,290).
10 In GFC's however, these perforations and the conduits they
11 form are disproportionately large compared to the size of
12 the fuel cell ceramic they serve. In the prior art, each
13 fuel cell electrode was served either by small internal
14 conduits or in some cases external manifolds. (See Fig. 1,
15 US Patent No. 6,500,578). In the prior art, these conduits
16 and manifolds have been small in cross section, especially
17 compared with the surface area of the solid oxide ceramic
18 they were designed to serve. This has been universally the
19 case in the prior art because the size of the stack served
20 by any given set of conduits or manifolds has always been
21 relatively short. In the prior art, each stack is served by
22 its own set of conduits or manifolds, and they are,
23 therefore, sized only to accommodate the amount of air and
24 fuel needed by that particular stack. In the case of GFC's
25 however, the stack is designed to be as much as a thousand

1 feet long. The gas flow conduits serving the stack are
2 correspondingly much larger in absolute terms and very much
3 larger in proportional terms, which is to say in relation to
4 the area of the ceramic wafer being served. The large sizes
5 of the GFC conduits allow air, fuel, and exhaust streams to
6 pass freely in and out of the stack over comparatively great
7 lengths.

8 GFC stack modules are unique in that they are designed
9 to be coupled together end-to-end. The modules have a male
10 end which is oriented pointing down toward the bottom of the
11 borehole, and female end which points up. The male end, is
12 threaded and equipped with a keyed plug. This plug is
13 inserted into a corresponding receptacle on the female end.
14 The key on the plug fits a corresponding slot in the
15 receptacle, forcing the modules to join in perfect
16 alignment, maintaining the orientation of the conduits
17 within the stack. The female end is fitted with a mating
18 collar which screws onto the threads of the male end. When
19 tightened, this collar forces the two modules together,
20 forming a gas-tight seal between the module ends, thus
21 allowing modules to be joined together to form uniquely long
22 stacks.

23 Another unique feature of GFC modules is the
24 arrangement of the compression bolts within the stack. The
25 use of compression bolts or "tie rods" to maintain seals

1 between interconnect plates in fuel cell stacks is a common
2 feature of the art, see US Pat. No. 6,372,372. The
3 arrangement of compression bolts in GFC stacks is unique and
4 is one of the features that allows the stacks to be
5 assembled end to end. In GFC stacks, the compression bolts
6 are contained within the body of the stack itself, rather
7 than being external to the stack, which is a common feature
8 of the prior art. This feature in combination with unique
9 aspects of the stack end caps, enables the linear connection
10 of GFC modules. Both the male and female module end caps,
11 are constructed of metal or other suitable material thick
12 enough so that holes for the compression rods can be
13 counter-sunk into the end caps. Counter sinking the bolt
14 holes enables the nut/washer assemblies at the end of each
15 bolt to be tightened onto the cap and into the countersinks,
16 thus leaving the end of the cap flush, so that it can butt
17 up against the opposing cap and form a seal.

18 The above and other features and advantages of the
19 present invention will become even clearer from the detailed
20 description of a specific illustrative embodiment thereof,
21 presented below in conjunction with the accompanying
22 drawings.

23

24

25

1 **BRIEF DESCRIPTION OF THE DRAWINGS**

2 Figure 1 is a plan view of the anode (positive) side of
3 the ceramic electrode wafer.

4

5 Figure 1A is an elevation view of the ceramic electrode
6 wafer.

7

8 Figure 1B is an enlarged elevation view of a portion of
9 the ceramic electrode wafer.

10

11 Figure 2 is a perspective view of the cathode side of
12 the fuel cell interconnect plate.

13

14 Figure 2A is a plan view of the cathode side of the
15 fuel cell interconnect plate.

16

17 Figure 2B is a plan view of the anode side of the fuel
18 cell interconnect plate.

19

20 Figure 2C is a cross section of the fuel cell
21 interconnect plate of Figure 2A across the line C-C

22

23

1 Figure 2D is an enlarged perspective view of the air
2 channels on the cathode side of the fuel cell interconnect
3 plate.

4

5 Figure 3 is a plan view of the anode gasket.

6

7 Figure 3A is a cross sectional view of the anode gasket
8 of Figure 3 taken across line A-A.

9

10 Figure 4 is a plan view of the cathode gasket.

11

12 Figure 4A is a cross sectional view of the cathode
13 gasket of Figure 4 taken across line B-B.

14

15 Figure 5 is a plan view of the electrolyte gasket.

16

17 Figure 5A is a cross sectional view of the electrolyte
18 gasket of Figure 5 taken across line C-C.

19

20 Figure 6 is an exploded perspective view of a
21 Geothermic Fuel Cell assembly.

22

23 Figure 6A is a perspective view of a Geothermic Fuel
24 Cell.

25

1 Figure 7 is a perspective view of a partial (6 cell)
2 Geothermic Fuel Cell stack.

3

4 Figure 8 is a perspective view of the female module
5 coupling.

6

7 Figure 8A is plan view of the female module coupling.

8

9 Figure 8B is an elevation view of the female module
10 coupling.

11

12 Figure 9 is an elevation view of the male module
13 coupling.

14

15 Figure 9A is a plan view of the male module coupling.

16

17 Figure 9B is a perspective view of the male module
18 coupling.

19

20 Figure 10 is an exploded perspective view of a
21 Geothermic Fuel Cell Module assembly.

22

23 Figure 10A is a perspective view of a Geothermic Fuel
24 Cell Module.

25

1 Figure 11 is a perspective view of Geothermic Fuel Cell
2 Spacer.

3

4 Figure 11A is an elevation view of a Geothermic Fuel
5 Cell Spacer.

6

7 Figure 12 is a plan view of two mated Geothermic Fuel
8 Cell Modules.

9

10 Figure 12A is a cross-sectional view taken along line
11 A-A of Fig. 12, of a section of two mated Geothermic Fuel
12 Cell Modules.

13

14 Figure 13 is a plan view of Geothermic Fuel Cell
15 Modules installed in a resource.

16

17 Figure 13A is a cross-sectional view taken along line
18 A-A of Fig. 13 of Geothermic Fuel Cell Modules installed in
19 a resource.

20

21 Figure 14 is an elevation view of a two-module stick of
22 mated Geothermic Fuel Cell Modules.

23

24 Figure 14A is a perspective view of a two-module stick
25 of mated Geothermic Fuel Cell Modules.

1
2 Figure 14B is an elevation view of a six-module stick
3 of mated Geothermic Fuel Cell Modules.

4
5 Figure 14C is an elevation view of a two-stick string
6 of GFC Modules.

7
8 Figure 15 is an elevation view of the internal
9 components of the heat-exchange manifold.

10
11 Figure 15A is a perspective view of the internal
12 components of the heat-exchange manifold.

13
14 Figure 15B is an enlarged perspective view of the
15 conduit bundle at one end of the heat exchange manifold.

16
17 Figure 16 is an exploded elevation view of one end of
18 the heat-exchange manifold assembly.

19
20 Figure 16A is an exploded perspective view of one end
21 of the heat-exchange manifold assembly.

22
23 Figure 16B is a plan view of one end of the heat-
24 exchange manifold.

25

1 Figure 17 is a perspective view of the female heat-
2 exchange manifold coupling.

3

4 Figure 18 is a perspective view of the male heat-
5 exchange manifold coupling.

6

7 Figure 19 is an elevation view of one heat-exchange
8 manifold module.

9

10 Figure 20 is a perspective view of the female/heat-
11 exchange manifold end of the heat-exchange manifold to fuel
12 cell stack transition coupling.

13

14 Figure 20A is perspective view of the male/fuel cell
15 stack end of the heat-exchange manifold to fuel cell stack
16 transition coupling.

17

18 Figure 20B is a perspective view of the internal
19 components of the heat-exchange manifold end of the heat-
20 exchange manifold to fuel cell stack transition manifold.

21

22 Figure 20C is a perspective view of the internal
23 components of the fuel cell stack end of the heat-exchange
24 manifold to fuel cell stack transition manifold.

25

1 Figure 21 is a perspective view of the bottom
2 plug/current return coupling assembly.

3

4 Figure 21A is a perspective view of the underside of
5 the bottom plug/current return coupling assembly.

6

7 Figure 22 is an elevation view of the end of a string
8 module and current return cable.

9

10 Figure 22A is an enlarged elevation view of the current
11 return cable coupling.

12

13 Figure 23 is a cross sectional view of a borehole
14 drilled into a resource formation.

15

16 Figure 24 is a cross sectional view of a borehole with
17 a schematic representation of a Geothermic Fuel Cell
18 installation.

19

20 Figure 25 is a cross sectional view of a borehole with
21 a schematic representation of the Geothermic Fuel Cell
22 process.

23

1 Figure 26 is a cross sectional view of a borehole and
2 production well with a schematic representation of the
3 Geothermic Fuel Cell process loop.

4

5 Figure 27 is a plan view of the layout of GFC heater
6 wells surrounding a production well.

7

8 Figure 28 is a plan view of a GFC production field with
9 six heater wells operating.

10

11 Figure 29 is a plan view of a GFC production field with
12 24 heater wells operating.

13

14 Figure 30 is a perspective view of an alternative
15 embodiment of the GFC interconnect plate.

16

17 Figure 31 is a plan view of an alternative embodiment
18 of the manifold.

19

20 Figure 31A is an exploded perspective view of an
21 alternative embodiment of the manifold.

22

23 Figure 32 is a perspective view of an alternative
24 embodiment of the present invention.

25

1 Figure 32A is a perspective view of another alternative
2 embodiment of the present invention.

3

4 Figure 33 is a schematic diagram of the simplified
5 electrical circuit of a GFC installation.

6

7 Figure 34 is a perspective view of an alternative
8 embodiment of a GFC interconnect plate.

9

10 Figure 35 is a perspective view of another alternative
11 embodiment of a GFC interconnect plate.

12

13

14 **DETAILED DESCRIPTION OF THE DRAWINGS**

15 Here, and throughout, the term "fuel" is intended to
16 comprehend any of those fluids— usually in gaseous
17 phase—which might serve as a chemical energy source for the
18 subject fuel cells. Said fuels include, but are not limited
19 to: hydrogen, natural gas, methane, carbon-monoxide;
20 hydrocarbons of various molecular weights - propane, butane,
21 etc.; vaporized fuels that are normally liquid at room
22 temperatures - gasoline, kerosene, etc.; mixtures of various
23 gases like "refinery gas", "coal gas", "bio-gas", etc.;
24 and novel substances and mixtures that are not normally

1 considered to be fuels, like process off gases from
2 destructive distillation of recycled tires, etc.

3 The term "air" is used here and throughout in its
4 general sense as an oxidant fluid—almost universally in its
5 gaseous phase—containing some fraction of the element
6 oxygen. The oxygen fraction of air is variable, but is here
7 intended to comprehend all fractions including 100% oxygen.
8 Said oxidants may or may not contain fractions up to and
9 including 100% of oxygen bearing chemical compounds like
10 carbon dioxide, carbon monoxide, and others.

11 The term "planetary surface" or "surface" as used
12 here means at or near the surface of the Earth or other
13 planetary body including the subsurface up to depths typical
14 of the installation of pipelines, tanks, and other
15 infrastructure which is generally installed beneath the
16 immediate surface of a planet and is not necessarily exactly
17 congruent with the surface. The same applies to the space
18 immediately above a planetary surface. So that the terms
19 "planetary surface" and "surface" can be taken to mean
20 anything within a hundred feet, more or less, below or above
21 a planetary surface.

22 The term "electrode" or "ceramic electrode wafer" or
23 "electrode wafer" as used here is intended to comprehend
24 both the individual electrodes that typically comprise a
25 fuel cell, namely the anode and the cathode, but also to

1 comprehend the assembly of the electrodes together with the
2 electrolyte that separates them.

3

4 FIGS. 1, 1A, 1B show the fuel cell ceramic 1000. This
5 is a thin, round ceramic wafer with d_1 equal to
6 approximately 2 inches, and $d_2 \approx .05$ to .1 inches. It is
7 composed of three materials. The first layer 10 comprises
8 the electrode's anode, + side, and is made of nickel-doped
9 Yttria Stabilized Zirconia (YSZ) or other suitable material.
10 The anode layer is porous (20-40%) and thin - $d_3 \approx .025$ to
11 .075 inches. The middle layer 20, comprises the electrolyte
12 layer; it is made of impermeable YSZ or other suitable
13 material, and is thinner than the anode - $d_4 \approx .001$ to .01
14 inches. The third layer 30 is the cathode, - side, made of
15 Strontium-doped Lanthanum Magnetite or some other suitable
16 material, and is typically thinner than the anode - $d_5 \approx .02$
17 to .05 inches. Such ceramic composites are a feature common
18 to solid oxide fuel cells and are well known in the art, see
19 U.S. Patent No. 6,051,329. Many different compositions and
20 thicknesses are viable alternatives for Geothermic Fuel
21 Cells, and those specified here are intended only to be
22 representative and not particular. See James Larminie and
23 Andrew Dicks, *Fuel Cell Systems Explained*, (New York: John
24 Wiley & Sons Ltd., 2000) p.164 - 168. When operating, the
25 fuel cell wafer 1000 will preferably exhibit a power density

1 of .1 to 1 Watts/cm², and a power output of 5 Watts. The
2 term "wafer" as used herein refers to a dual electrode
3 device-anode electrolyte cathode-as depicted in FIG. 1.

4

5 FIGS. 2 - 2D show the interconnect plate 1020. The
6 interconnect plate 1020 serves a number of purposes: It is
7 the substrate on which the ceramic electrode wafer 1000
8 rests, and the plate 1020 provides electrical contact to
9 both sides of the fuel cell wafer 1000. The interconnect
10 plates, when stacked up as shown in FIG. 7, also form the
11 conduits for fuel, air, and exhaust that must be
12 communicated to and from the electrode wafers 1000. Holes,
13 1 through 4, measuring from one to two inches in diameter,
14 d, = 1.7 in., pass completely through the interconnect
15 plates 1020, to form said conduits, when properly aligned.
16 Each plate 1020 has two holes 1 for the air conduits, one
17 hole 2 for the fuel exhaust conduit, two holes 3 for the air
18 exhaust conduits, and one hole 4 for the fuel conduit.
19 (Gaseous fuel passing through the fuel conduit can be
20 natural gas, methane, "refinery gases" such as butane,
21 propane, etc., suitable off-gases harvested from the heated
22 resource formations, or other suitable gaseous fuel.) Note
23 that there are two conduits each for air intake and air
24 exhaust, due to the larger relative quantities of air
25 compared to fuel required to sustain power output by the

1 fuel cells. There are a further six, smaller, holes 5 for
2 the stack compression bolts (see FIG. 10) $d_{10} = .4$ in. Each
3 plate 1020 has two sides: the cathode side C and the anode
4 side A, corresponding to the sides of the electrode wafer
5 1000 contacted by the plates. Two channels 6 etched in the
6 surface of the cathode side C of the interconnect plate 1020
7 allow air from the air conduits to reach a network of
8 channels 60. This network of air channels 60 (see
9 enlargement FIG. 2D) forces the circulating air to follow a
10 circuitous route across the plate, thereby feeding air to
11 every part of the cathode 30. This area of etched channels
12 60 measures $d_8 = 1.7$ in., slightly smaller than the diameter
13 of the electrode wafer 1000. The channels are of width, d_{11}
14 = .1 in. and depth, $d_{12} = .03$ in. The cathode side 30 of the
15 wafer 1000 is in contact with those parts of the plate that
16 have not been etched 61 to form air channels 60. These
17 unetched areas, ridges 61, support the electrode wafer 1000
18 and provide electrical contact with the cathode side of the
19 wafer. On the anode side A of the plate 1020, see FIG. 2B,
20 a single channel 7 allows fuel to pass from the fuel conduit
21 4 to a network of fuel channels 70. The gaseous fuel is
22 forced by the channels 70 to follow a long route which
23 brings the fuel into contact with all areas of the anode 10.
24 As on the cathode side, the unetched areas, ridges 71, form
25 the areas of contact between the interconnect plate 1020 and

1 the anode side of the wafer 1000. The plates 1020 are
2 approximately 7.5 inches in diameter, $d_6 = 7.5$ in., and are
3 approx. .18 in. thick, $d_7 = .18$ in. The plates 1020 can be
4 made of steel or ceramic or other suitable material having
5 the desired characteristics of heat resistance and
6 electrical conductivity.

7

8 FIGS. 3, 3A show the anode gasket 1030. The gasket
9 1030 is the same diameter as the interconnect plate 1020, d_6
10 = 7.5 in., and the same thickness as the ceramic anode, $d_3 \approx$
11 .025 to .075 inches. The anode gasket 1030, together with
12 the other gaskets of the fuel cell assembly, 1040 & 1050,
13 (see FIGS. 4 - 5) provides gas-tight seals and electrical
14 insulation between the interconnect plates 1020. The anode
15 gasket and the other gaskets have holes 1 - 5 in common with
16 the holes in the interconnect plates 1020. In addition, the
17 anode gasket has a hole in the center 9, $d_{13} = 2$ in., to
18 accommodate the anode side 10 of the fuel cell ceramic 1000.
19 The anode gasket also provides a route of egress for spent
20 fuel from the anode. Fuel exhaust leaves the anode by way
21 of a gap 11 in the gasket 1030, which provides communication
22 between the anode and the hole for the fuel exhaust conduit
23 2. The gaskets maintain their seals by means of compressive
24 forces applied to the fuel cell stack by bolts passing
25 through holes 5 (see FIG. 10). Accordingly, the gaskets are

1 made of ceramic, glass, mica, or other suitably insulative
2 material which remains solid at the operating temperatures,
3 750 - 1000° C., of the stack.

4

5 FIGS. 4, 4A show the cathode gasket 1040. The cathode
6 gasket is the same diameter as the anode gasket and the same
7 thickness as the cathode layer 30 of the fuel cell ceramic
8 1000, $d_5 \approx .02$ to .05 inches. The cathode gasket 1040 has
9 holes 1-5 in common with the anode gasket 1030 and
10 interconnect plates 1020, and hole 9 in common with the
11 anode gasket 1030. The cathode gasket provides a route of
12 egress for air exhausted from the cathode. Air exhaust
13 leaves the cathode by way of two gaps 12 in the gasket 1040,
14 which provide communication between the cathode 30 and the
15 holes for the air exhaust conduits 3.

16

17 FIGS. 5, 5A show the electrolyte gasket 1050. The
18 electrolyte gasket has holes 1-5 and 9 in common with the
19 other gaskets, but has no gaps. The electrolyte gasket is
20 the same thickness as the electrolyte layer of the fuel cell
21 ceramic, $d_4 \approx .001$ to .01 inches.

22

23 FIGS. 6, 6A show one complete cell assembly 400. FIG.
24 6 shows an exploded view of a one-cell assembly 400. The
25 assembly consists of two interconnect plates 1020; three

1 sealing gaskets: the anode gasket 1030, the cathode gasket
2 1040, and the electrolyte gasket 1050; and the ceramic wafer
3 1000. The ceramic wafer 1000 sits in the hole at the
4 center of the middle gasket 1050, and the gaskets are
5 sandwiched between the interconnect plates 1020 forming a
6 complete single fuel cell 400.

7

8 FIG. 7 shows a number of individual cells 400 assembled
9 and aligned to form the beginning of a fuel cell stack 600.
10 It can be seen how the holes in the plates and gaskets, 1
11 through 4, when aligned, begin to form conduits 199 - air
12 conduits, 299 - fuel exhaust conduit, 399 - air exhaust
13 conduits, & 499 - fuel conduit, for the passage of gases in
14 and out of the fuel cell stack. Note that each interconnect
15 plate 1020 acts as the top of one cell and the bottom of the
16 next cell in the stack. The stack "pitch", which is to
17 say the number of cells per vertical inch of stack, is
18 approximately 3.8 cells per inch, or 46 cells per foot of
19 stack. Nominal thickness of the cells is $d_{14} \approx .26$ in. In
20 completed Geothermic Fuel Cell Modules (see FIG. 10, 900)
21 useful in the field, the stack 600 will be about five feet
22 high, more or less, and will comprise about 230 cells.

23

24 FIGS. 8, 8A, 8B show the female end coupling 700 for
25 the Geothermic Fuel Cell (GFC) Module 900. Each end of each

1 GFC module 900 is mounted with a fitting that enables the
2 modules 900 to be coupled together end-to-end. The female
3 end coupling 700 comprises a plate 18 that has holes 1 - 5
4 in common with the fuel cell assemblies 400, forming
5 continuations of the stack conduits 199, 299, 399, and 499.
6 The coupling plate 18 is sufficiently thick so that
7 countersunk holes 20 can be drilled into the face of the
8 plate allowing clearance for nuts and washers mounted on
9 compression bolts installed in holes 5 (see FIG. 10). The
10 thickness of the plate also allows the creation of a
11 counter-sunk receptacle 21. This receptacle receives a
12 corresponding contact plug 25 mounted on the male coupling
13 800 (see Fig. 9). The receptacle 21 is grooved 210 to
14 receive an aligning key 250 on the male plug. Surrounding
15 the coupling plate 18 is a coupling flange 17 that retains a
16 threaded mating collar 16, while allowing the mating collar
17 to turn freely. The mating collar 16 is retained at the
18 female end of the module by a fixed retaining ring 15. A
19 section of casing 19 abuts the middle section of the fuel
20 cell stack casing. The casing is $d_{15} = 8$ in, and the wall
21 thickness is .25 in, more or less.

22

23 FIGS. 9, 9A, 9B show the male end coupling 800 for the
24 Geothermal Fuel Cell module. Like the female end coupling
25 700, the male coupling has a plate 22 with countersunk holes

1 20 & 5 for compression bolts, and holes, 1 - 4, for the gas
2 conduits 199, 299, 399, & 499. The male end coupling 800 is
3 threaded 24 to join to the female end mating collar 16 (see
4 FIG. 8). There is a raised contact plug 25 that is keyed
5 250 to join the receptacle 21 on the female end and maintain
6 alignment of the modules. The key 251 fits the groove 210
7 in the female receptacle, insuring proper alignment. The
8 keyed plug 25 is electrically conductive and provides
9 electrical contact between modules. The male coupling
10 threads 24 are mounted to a section of casing 19 that butts
11 to the middle section of the stack module casing (see FIG.
12 10). Nominal diameter of the casing is the same as on the
13 female coupling, $d_{15} = 8$ in. and wall thickness is the same,
14 .25 in.

15

16 FIGS. 10, 10A show a complete Geothermic Fuel Cell
17 module 900. FIG. 10 is an exploded view of the module
18 components. The fuel cell stack 600 comprises 200 too 250
19 individual fuel cells 400, and measures around five feet in
20 height, $d_{17a} \approx 60$ in. A section of tubular casing 19
21 surrounds the fuel cell stack 600. The casing 19 is made of
22 steel, ceramic, or other suitable material and may be lined
23 with electrical insulation if necessary. The stack casing
24 19 serves a number of functions: first, it protects the
25 stack 600 when the otherwise fragile assembly is lowered

1 into the ground; second, it helps maintain sealing around
2 the edges of the stack; third it helps maintain compressive
3 force on the interconnect plates within the stack by
4 restricting their ability to creep horizontally; and finally
5 the casing 19 improves the module's physical rigidity and
6 capacity to bear loads while being installed in the
7 borehole. The casing 19 is of the same dimensions as the
8 sections of casing on the female coupling and the male
9 coupling, $d_{15} = 8$ in. and wall thickness = .25 in. The
10 female coupling 700 and the male coupling 800 go at their
11 respective ends of the stack 600. Oriented relative to a
12 vertical borehole, the male coupling 800 points down, toward
13 the bottom of the hole, and the female coupling 700 points
14 up. There are six compression bolts 27 which are installed
15 in holes 5 and pass through the couplings and the stack from
16 end to end. The bolts 27 are insulated by a coating of
17 suitable insulation or alternatively are inserted in sleeves
18 2701 (see Figs. 10B & 10C) of ceramic or other suitably
19 insulating material. The ends of the compression bolts,
20 also referred to in the art as "tie rods", are threaded
21 and receive nuts 28 and washers 29. The washers 29 are made
22 of ceramic or other suitably insulating material. The nuts
23 28 are tightened on the bolts 27 until they are countersunk
24 at least flush with the ends of the coupling plates 18 & 22.
25 When assembling the modules, additional insulating material

1 in the form of glass paste and/or ceramic sleeves may be put
2 in place around the nuts and threads to further isolate them
3 electrically from the stacks. The bolts 27 compress the
4 components of the module together, creating gas-tight seals
5 between the fuel cells 400 and binding the module into a
6 single cohesive unit, the Geothermic Fuel Cell module 900.

7 In this configuration the GFC Module is suitable for
8 heating ground formations which can absorb up to 750
9 BTU/ft./hr. from a hole approximately one foot in diameter.
10 It is known in the art (see U.S. Patent No. 4,886,118) that
11 oil shale, for example can be heated at the rate of 785
12 BTU/ft./hr., (230 Watts/ft.). The exemplary GFC stack shown
13 here will produce useful thermal energy at that rate when
14 operated at the appropriate temperature, between 750 and
15 1000° C., for example.

16 Fuel cells of the preferred type, solid oxides, do not
17 require the noble metal or other catalysts that other fuel
18 cell types often require. However, solid oxide fuel cells
19 will only operate at temperatures sufficiently high to
20 render the electrolyte conductive to oxygen ions, typically
21 800° C. or higher. (see Larminie & Dicks, p. 164.)
22 Therefore, it is necessary to pre-heat the GFC stack 600,
23 prior to commencing operation of the fuel cells. In the
24 preferred pre-heating method, the GFC stack 600 is brought
25 up to operating temperature by pre-heating air (or other

1 fluids) in a surface burner and communicating the resulting
2 hot fluids to the stack 600 through the manifold sections
3 1500. The hot fluids are then circulated through the stack
4 600, raising its temperature. In an alternative method, the
5 stack is pre-heated by means of running electrical current
6 through the stack via the external electrical circuit (see
7 Fig. 33). By increasing the strength of the electrical
8 current, amperage, the resistance of the stack will cause
9 the stack to heat. Once operating temperature has been
10 achieved, the external flow of current will be terminated.

11 Once the stack has reached the desired temperature,
12 between 750 and 1000° C, fuel is then supplied to the cell
13 anodes via conduit 499. The fuel cells 400 in the stack 600
14 then operate in the manner well established in the art,
15 producing electricity and heat. The electricity is a co-
16 product which leaves the stack via electrical conduction
17 through interconnect plates and conductive couplers and
18 additional conductors (see FIGS. 16, 18 & 33). The heat is
19 absorbed by the ground via solid-to-solid thermal conduction
20 (see FIGS. 13, 26 and 28).

21

22 FIGS. 11, 11A show a spacer plate 1100. The spacer
23 plate is placed in the stack to replace one or more
24 interconnect plates 1020. If the formation to be heated
25 cannot absorb the amount of thermal energy produced by a

1 nominal stack 600, then spacer plates, $d_{16} \approx .5$ in., can be
2 introduced to the stack at the time of manufacture. The
3 spacer plates have holes 1-5 in common with the interconnect
4 plates 1020, but otherwise none of those features necessary
5 to accommodate a fuel cell wafer 1000. In this respect the
6 spacer plate is an inert component of the stack and serves
7 to reduce the stack's power density, and accordingly its
8 thermal output. The spacers allow GFC stacks to be
9 specifically tailored to produce heat in quantities and in
10 vertical profiles that closely match the characteristics of
11 a given resource. For example, yields of oil by Fischer
12 Assay vary considerably over thick horizons of oil shale.
13 Oil shale at a depth of 1200 feet might assay at a yield of
14 40 gallons per ton, while oil shale at 1220 feet might only
15 assay at 5 gallons per ton. With the spacers in the stack
16 it will be possible to tailor the stack so that it produces
17 more heat in richer zones while producing relatively little
18 or no heat in barren zones. It may be feasible to directly
19 correlate data on the resource from cuttings or rock cores
20 obtained when boreholes (see FIG. 23) are drilled, with
21 assembly of the fuel cell stacks 600 at the factory, thereby
22 tailoring each stack to the specific depth of the particular
23 borehole where it will be installed. Since the spacers and
24 the fuel cells 400 are both standardized in their
25 construction, and therefore can be mass produced at lower

1 unit costs, this ability to tailor the stack by means of
2 standard spacers allows GFCs to take advantage of economies
3 of scale in cell production, while still producing tailored
4 stacks.

5 GFCs are unique among fuel cells in that they are
6 designed from the ceramic wafer 1000 outward, through the
7 interconnect plates 1020 and their self contained exhaust
8 circulatory conduits 199, 299, 399, 499 to the casing 19, to
9 function as both electric generators and as heaters. The
10 power densities of GFCs, for example, even without the
11 addition of spacers 1100, as above, are typically very low
12 as compared with the power densities of most fuel cell
13 stacks described in the art. An exemplary GFC stack 600, as
14 configured here for oil shale production, has a power
15 density of somewhat less than 190 Watts/ft³. Compared to
16 fuel cells for mobile applications, which exhibit stack-only
17 power densities of 5 to 15 kilo Watts/ft³, it can be seen
18 that GFCs are uniquely configured for other purposes--
19 specifically heating the ground.

20

21 FIGS. 12, 12A show an example of a section of GFC stack
22 with spacer's 1100 integrated to tailor the stack's heat
23 production to match the characteristics of the formation in
24 which the stack is installed. FIG. 12A is a cross section
25 of a portion of two assembled GFC Modules 900, coupled

1 together by the female coupling 700 and the male coupling
2 800. The male conducting plug 25 fits in the female
3 receptacle 21. The mating ring 16, which is kept on the
4 female coupler 700 by the fixed retaining ring 15, screws
5 onto the threads 24 of the male coupler 800 and when
6 tightened pulls the two modules 900 together, forming a gas-
7 tight seal between the modules so that gases can pass along
8 the conduits 299 and 499. The casing 19 surrounds the fuel
9 cell stack 600. The stack 600 is here comprised of fuel
10 cells 400, composed of gaskets 1030, 1040, 1050; the ceramic
11 wafers 1000; interconnect plates 1020; and spacers 1100.
12 The proportion of spacers to fuel cells may be varied as
13 desired to match the thermal characteristics of any given
14 target resource formation.

15

16 FIGS. 13, 13A show a Geothermic Fuel Cell module (also
17 called a "segment" 900 installed in a resource formation.
18 Figure 13A is a cross section showing the borehole 300 (see
19 FIG. 23) lined with borehole casing 34, and containing the
20 vertically oriented Geothermic Fuel Cell module 900. (Note
21 that other orientations of GFC modules, including horizontal
22 installations, are both feasible and contemplated.) The
23 well casing 34 is of the type typically found in oil and
24 natural gas wells. The casing here supports a borehole 300
25 nominally a foot or so in diameter, $d_{15A} = 12$ inches. The

1 borehole has been drilled through overlying barren rock
2 formations, "overburden", (see Fig. 23). Typically the
3 oil yielding and other formations of interest for treatment
4 with Geothermal Fuel Cells 900 are between 100 and 1000 feet
5 beneath the surface. Some overburden is desirable in order
6 to prevent heat from reaching the surface. Resources under
7 more than a 1000 feet of overburden may not be economical.
8 The casing 19 of the modules 900 and the casing 34 of the
9 borehole form between them an annular space AS. This space
10 is filled with a suitable grout 35 possessing the desired
11 properties of strength, thermal conductivity, and electrical
12 insulation. A single Geothermal Fuel Cell module 900 is
13 shown coupled to modules above and below it, partially
14 shown. The male coupling 800 and female coupling 700 are
15 threaded together to join the modules 900. Fuel passes into
16 the fuel cell stack 600 through the fuel conduit 499, fuel
17 exhaust passes out of the stack via conduit 299.

18 Electrochemical reactions of the fuel on the anodes of
19 the fuel cell wafers 1000 liberate energy in the forms of
20 free electrons and heat. These reactions are well known in
21 the art. Energy in the form of electricity, flowing along
22 the path of continuous conductivity established by the
23 interconnect plates 1020 of the stack 600 and the coupling
24 hardware 700 and 800 creates a useful current (see Fig. 33)
25 that is utilized in some economically beneficial manner,

1 e.g., sold onto the power grid, used on site for some
2 industrial purpose, or sent to electrical resistance heaters
3 which may be used to further heat the ground. The heat
4 produced by the fuel cells 400 is absorbed by the ground,
5 thereby increasing in temperature. Solid-to-solid thermal
6 conduction provides a path for heat migration into the
7 ground. Thermal energy produced at the anodes 10 heats the
8 interconnect plates 1020 which heat the module casing 19
9 which heats the conductive grout 35 which then heats the
10 well casing 34. The hot well casing 34 heats the ground.
11 As heat flows from the stack 600 to the ground the
12 temperature of the stack and the surrounding shale or sand
13 or other formation comes into equilibrium with the stack.
14 Since the stack operates at a temperature of between 750 and
15 1000° C., the temperature of the resource formation
16 immediately adjacent to the wellbore casing 34, is also
17 raised to that temperature. As heat continues to be
18 produced in the fuel cells, a heated zone expands around the
19 borehole. The maximum temperature of the resource is of
20 course the same as the temperature of the fuel cell stack
21 600, which is to say 750 to 1000° C. This isotherm of
22 maximum heat, "heat front", moves slowly into the
23 formation at rates determined by the thermal conductivity
24 and specific heat of the ground, and other factors. Ground
25 heating by solid conduction, a process referred to here as

1 "geothermics", is known in the art. Particular rates of
2 formation heating are dependent on a number of factors but
3 an example calculated from field testing data is given in
4 U.S. Patent No. 4,886,118, FIG. 8: Heaters, 10 feet apart,
5 operated at 230 Watts/ft. (785 BTU/hr./ft.) moved the 300°
6 isotherm ("heat front") 10 feet in three months.

7

8 FIGS. 14, 14A show two Geothermal Fuel Cell modules 900
9 joined together, $d_1 \approx 10$ ft. Multiple joined modules
10 constitute a "stick" of modules 2000. A "stick" of pipe,
11 in drilling parlance, is a number of sections of drill stem
12 preassembled and put in the rack of a drilling rig.
13 Normally sticks on most drill rigs are around 60' in length.
14 It is contemplated that 30' is around the optimum length for
15 sticks of geothermal fuel cells due to their heavier weight
16 compared to normal drilling pipe. Such a 30 foot stick
17 would be constituted of six modules (see Fig. 14B). It is
18 anticipated that 30 foot sticks will be preassembled in the
19 factory and then will be sealed and shipped to the field
20 where they will be mated with other sticks and installed
21 into boreholes. The object being to automate assembly to
22 the greatest extent possible and to make installation
23 feasible with conventional oil and gas drilling equipment.
24 In the field, it is anticipated that sticks will be joined
25 together, forming "strings" 9000 (see FIG. 14C) of modules

1 up to 500-1000 feet in length. A 500 foot string would
2 comprise 16 preassembled sticks made up of 100 modules 900.
3 Such an installation would generate about 100 kiloWatts of
4 electric power and would have a useful thermal output on the
5 order of 375,000 BTU/hr.

6 FIG. 14B shows an elevation view of six GFC modules 900
7 assembled into one pre-fabricated "stick" 2000, $d_{17b} \approx 30$
8 ft.

9 FIG. 14C shows an elevation view of two six-module
10 sticks 2000 joined to create a 12 module "string" 9000,
11 $d_{17c} \approx 60$ ft. Strings of GFC modules can be scaled up to
12 lengths as great as 1000 feet by adding additional sticks.

13

14 FIGS. 15, 15A, 15B show internal components of the
15 manifold, also referred to as the "heat exchanger", or the
16 "heat exchange section" 1500 (see FIG.19). The manifold,
17 is composed of a number of conduits, which form passages for
18 the movement of fluids between the fuel cell stack 600 and
19 the planetary surface. In the preferred embodiment, depicted
20 here without any casing 19, the conduits comprise a bundle
21 of tubes 1366. Here, these tubes are shown as 151 through
22 154, forming continuations of the conduits 199, 299, 399,
23 and 499, running through the fuel cell stacks 600. In
24 addition to these gas flow conduits, there is an additional

1 conduit 155 in the manifold which serves as a passage for an
2 insulated electrical line 160 (see FIG. 16).

3 The primary function of the manifold is to provide
4 communication between the down-hole fuel cell stack 600 and
5 the surface, and in the preferred embodiment, the manifold
6 also functions as a heat-exchanger. The tubes 151 - 155 are
7 made of steel, copper, or some other suitable heat
8 conducting material. The tubes are nominally 2 in. in
9 diameter, $d_{15b} = 2$ in. The tubes are in physical contact,
10 thereby facilitating heat exchange between the gases
11 traveling in the various tubes. The tubes are positioned
12 and held in place by round brackets 156 that are installed
13 at regular intervals along the length of the manifold. The
14 counter-flow of these gases in alternating tubes (FIG. 15B)
15 facilitates the exchange of heat between them so that
16 outgoing gasses are cooled and incoming gasses are warmed as
17 they pass through the heat exchange section. The heat
18 exchanger tubes 151 - 155 and the conduits in the fuel cell
19 stacks 199, 299, 399, & 499 are so arranged that there is an
20 alternate flow of cool and hot gases in each adjacent
21 conduit. For example, air from the surface flows through
22 conduits 199, which are on either side of conduit 299
23 through which flows the hot fuel exhaust from the anode. In
24 the heat exchanger, these conduit tubes are in physical
25 contact, and residual heat from the fuel exhaust, on its way

1 out, warms the air on its way in. A similar arrangement
2 prevails between the air exhaust conduits 399 and the fuel
3 conduit 499. Depending on the resource, the heat exchange
4 section (Fig. 19, 1500) may be from 100 to 1000 feet in
5 length. It is anticipated that in shallow formations, or
6 due to other process constraints, it may be necessary to
7 pass the hot exhaust gases through additional heat
8 exchangers located on the surface. Thermal insulation 157 is
9 installed around the cluster of tubes 1366 to prevent heat
10 loss to the ground in the heat-exchange section. The heat
11 exchanger 1500 makes it possible to minimize loss of thermal
12 energy from the target formation through the exhaust
13 streams. Heat that would otherwise leave the ground with
14 exiting air and fuel exhaust is returned to the formation.
15 This increases the process' thermal efficiency. See FIG. 24
16 to view the relative installation of the heat exchanger 1500
17 above the string 9000 of fuel cell modules.

18 Alternative configurations of the manifold are
19 anticipated, both with and without heat exchange functions.
20 One such alternative is depicted in Figures 31 and 31A.

21

22 FIGS. 16, 16A, 16B show exploded views of the
23 manifold/heat exchanger assembly 1500. In the center of the
24 middle tube 155 is an electrical conductor 160 and
25 electrical insulation 161. The conductor, which is made of

1 copper, aluminum, or other suitable conductive material,
2 provides the path for the outgoing leg of the cells'
3 electrical circuit (see Fig. 33). The conductor 160 is of
4 sufficient cross section to accommodate the flow of
5 electrical current leaving the fuel cells 400. Surrounding
6 the conductor conduit 155 is a bundle of gas conduits, 151,
7 152, 153, and 154 carrying air, fuel, and exhaust into and
8 out of the fuel cell stack. Surrounding the bundle of tubes
9 1366 is a layer of thermal insulation 157. Circular
10 brackets 156 maintain alignment and positioning of the tubes
11 and hold the insulation in place. The entire heat exchanger
12 assembly 1500 is contained within a tubular casing 19.

13

14 FIG. 17 shows the female coupling 200 for the heat
15 exchanger. The female coupling includes a manifold plate
16 51 that has holes 1 - 4 in common with the fuel cell
17 interconnect plates 1020, forming continuations of the air,
18 gas, and exhaust conduits 199, 299, 399 and 499. Like the
19 female fuel cell module coupling 700, the female heat
20 exchange coupling 200 has a threaded mating collar 16. As
21 on the fuel cell modules, the collar 16 turns freely and
22 matches the threads 24 on the male heat exchange coupling
23 (Fig. 18, 300). The male and female couplings are threaded
24 together and tightened to provide a gas tight seal between
25 heat exchanger sections 1500. The center of the manifold

1 plate 51 is filled by a ring of electrical insulation 161
2 and a conductive receptacle 163. The receptacle 163 is
3 sized to accept the conductive plug 164 on the end of the
4 male coupling 300 (Fig. 18). When mated, the receptacle 163
5 and plug 164 provide an electrical connection between heat
6 exchanger sections 1500 (Fig. 19). The female coupling is
7 plugged onto an extension of the heat exchanger conductor
8 160 which fits into the lower half of the receptacle 163.
9 The under side of the manifold plate 51 butts against the
10 conduit tubes 151, 152, 153, and 154 (Fig. 15), and the
11 whole coupling is welded to the heat exchanger casing 19.

12

13 FIG. 18 shows the male heat exchanger coupling 300.
14 The male coupling 300 is threaded 24 to accommodate the
15 mating collar 16 on the female coupling. The male coupling
16 has a conductive plug 164 which fits into the corresponding
17 receptacle 163 on the female coupling. On the underside of
18 the plug 164 is a receptacle 163 that accommodates an
19 extension of the conductor rod 161. The male coupling is
20 plugged onto the conductor rod, and the casing 19 welded in
21 place in the same manner as the female coupling.

22

23 FIG. 19, shows a complete manifold/heat exchanger
24 assembly 1500 with mating collars 200, 300 in place, forming
25 a ready to install heat exchanger section. Heat exchanger

1 assemblies 1500 can be constructed in sections up to 60 feet
2 long (30 foot section, $d_{18} = .30$ ft., shown) and then will be
3 joined together into strings and installed in the bore holes
4 (see FIG. 24).

5

6 FIGS. 20, 20A show the mating manifold section 1800,
7 which mates the uppermost fuel cell stack module 900 to the
8 lowest heat exchanger section 1500 as shown in FIG. 24.
9 FIG. 20 shows the heat exchanger side HE of the mating
10 manifold 1800HE. FIG. 18A shows the fuel cell side FC. The
11 fuel cell side FC of the transition manifold 1800 FC is
12 fitted with a conductive male plug 25 which is inserted in
13 the corresponding receptacle 21 on the upper most female
14 fuel cell module coupling 700 (Fig. 8). Tubes, 151 - 154
15 form continuations of the air, fuel and exhaust conduits
16 199, 299, 399, and 499 from the fuel cell stack 600. This
17 allows the flow of gases unimpeded from the uppermost fuel
18 cell stack 600 into the lowest heat exchanger section 1500
19 and vice versa. Note that the tubes in the manifold section
20 converge (see FIGS. 20B & 20C) until they cluster together
21 around the electric conductor conduit 155. This arrangement
22 allows the tubes to make the transition from their dispersed
23 configuration in the fuel cells stacks 900 to their
24 clustered configuration in the heat exchanger section.
25 Clustering the tubes facilitates heat transfer between the

1 counter-flowing gases in the heat exchanger and also
2 increases the amount of volume available for insulation 157
3 (see FIGS. 15 & 16), which minimizes heat loss to the
4 overburden. Positioning of the tubes is maintained with
5 circular brackets 156. A mating collar 16 screws onto the
6 threads 24 on male coupling 300 at the bottom of the first
7 heat exchange section 1500. An extension of the electrical
8 conductor 160 plugs into a female receptacle 163 in the
9 mating manifold. This provides an electrical connection
10 between the fuel cell stacks 600 and the heat exchange
11 section 1500.

12

13 FIGS. 20B & 20C show the heat exchanger transition
14 manifold without casing 19 or couplers 200 & 300. With the
15 casing removed it is possible to see the convergance of the
16 conduits 151-154 as they pass from the fuel cell side of the
17 manifold 1800 FC to the heat exchanger side 1800 HE.

18

19 FIGS. 21, 21A show the current return cable/bottom plug
20 assembly 500. This assembly is installed at the lower,
21 male, end of the first GFC module 900 that is emplaced. The
22 bottom plug 500 has plate 55 that has no holes. The plug
23 assembly 500 is screwed onto the first GFC module forming a
24 gas-tight seal to the lower end of the fuel cell stack 600.
25 Plate 55 is thick enough to accommodate a countersunk

1 receptacle 21 which receives the corresponding male plug 25
2 on the male module coupling 800 (FIG. 9). An insulated
3 conductor 57 is bonded to the bottom of plate 55 (FIG. 21A).
4 The conductor 57 is fitted with a threaded mating collar 56
5 that is so arranged as to turn freely. There are cut-outs
6 58 in the bottom assembly casing 19 to accommodate
7 connection of an electrical cable 60 (FIG. 22) to the
8 conductor by means of the mating collar 56.

9

10 FIGS. 22, 22A show the electrical current return cable
11 60. In order for a fuel cell stack to operate, it is
12 necessary to create an electric circuit along which the
13 current may travel (see Fig. 33). Therefore, there must be
14 an electrical connection to the bottom of the fuel cell
15 stack. This is effectuated by an insulated current return
16 cable 60. The current return cable 60 is attached to the
17 bottom of the stack by means of a threaded plug 59. The
18 plug screws into the mating collar 56 (shown unplugged here
19 for clarity) to form an electrical connection between the
20 cable 60 and the fuel cell module 900. As modules are
21 installed in the borehole, the cable 60 is wound around the
22 module casing 19. The cable 60 can, if necessary, be
23 sheathed inside a flexible armored conduit which can then be
24 spot welded to the exterior of the module casing or attached
25 by other means.

1

2 FIG. 23 shows a cross section of the earth with a
3 borehole 300, roughly a foot or so in diameter, $d_{16} = 12$ in.
4 The "Resource" layer contains oil/gas or other volatiles
5 to be extracted. Resources as thin as five or ten feet D_{20}
6 $\approx 5\text{-}1000$ feet can be heated with GFC modules, and heating
7 resource beds up to 500 to 1000 feet thick is anticipated.
8 Below the resource layer is the "Underburden", and above
9 this layer is the "Overburden" $D_{19}, \approx 100\text{-}1000$ feet. The
10 borehole 300 starts at the "Planetary Surface" and usually
11 continues somewhat into the Underburden layer.

12

13 FIG. 24 shows the fuel cell string 9000 installed in
14 the borehole 300, and positioned so that the stack
15 terminates somewhat above the bottom of the Resource layer
16 that is to be heated. The manifold/heat exchanger 1500
17 passes through the Overburden layer. The heat exchanger
18 section 1500 is joined to the fuel cell string 9000 by the
19 transition manifold 1800. The fuel cell string 9000 is
20 terminated by the current return bottom plug 500.

21

22 FIG. 25 shows the casing 34 lining the inside of the
23 borehole 300 and supporting the hole. The annular space AS
24 between the fuel cell string 9000 and the borehole casing 34
25 in the Resource section is filled with grout (cement) 35

1 specifically formulated for thermal conductivity and
2 electrically insulating properties (see Fig. 33). In the
3 Overburden section a thermally insulating grout 36 surrounds
4 the heat exchanger 1500 and acts to conserve heat energy.
5 Schematically shown is fuel in 499, air in 199, exhaust out
6 299 & 399 and electricity out 255.

7

8 FIG. 26 shows the geothermic fuel cell (GFC) stack
9 operated on a feed of gaseous fuel produced from the
10 resource formation. As the GFC strings 9000 operate, they
11 produce electricity 2555 and heat 2600. The strings 9000
12 are configured and operated to produce useful heat at the
13 same rate the formation can absorb it. Heat from the stack
14 is absorbed by the Resource formation, and migrates through
15 the formation at a rate determined by the Resource's thermal
16 conductivity and other factors. As the temperature of the
17 Resource rises, noncondensable gases are evolved and
18 hydrocarbons are liquefied. Rising temperature leads to
19 order of magnitude decreases in viscosity of hydrocarbon
20 liquids. Gasification, liquification, and thermal expansion
21 all serve to pressurize the Resource formation. Rising
22 pressure forces the gaseous and liquid products to move away
23 from the heated zones. In non-porous resources like oil
24 shale, pressures are sufficient to create a network of
25 horizontal fractures. According to U.S. Patent No.

1 4,886,118 these fractures, or the natural porosity of the
2 formation, allow the establishment of communication between
3 the heated borehole 2501 and a nearby Production Well 2500.
4 Gas and oil are driven into the Production Well 2500 where
5 they are removed to the Surface. On the Surface, the oil is
6 collected for sale, and the gas is cleaned and conditioned
7 and then fed under pressure down the stack to the fuel cells
8 where its energy is released as heat and electricity. Once
9 communication has been established between the Heater Well
10 2501 and surrounding Production Wells 2500, and sufficient
11 gas has begun to flow to power the fuel cell stack, no
12 further input of outside fuel may be required to operate the
13 process.

14

15 FIG. 27 shows the arrangement of six heater wells 2501,
16 surrounding a single production well 2500. It is known in
17 the art that solid conduction heating of the ground may be
18 accomplished with heaters emplaced 30 to 100 feet from the
19 production wells (see US Patent 4,886,118). Actual spacing
20 of GFC heaters is dependant on the formation being developed
21 and other factors, like the properties of a target
22 hydrocarbon being produced. The embodiment of the invention
23 depicted here shows placement of the heater wells 2501 on 45
24 foot spacing (45' center to center, 44' casing to casing)
25 $d_{25} = 44'$. The wells are a foot in diameter and contain a

1 multiplicity of GFC modules, or "segments" 900, and a
2 number of heat-exchange sections or "manifolds" 1500
3 spanning the overburden (see Fig.24). A variety of spacing
4 patterns for the heater wells is known in the art, (see US
5 Patent 2,914,309, Figs. 1 - 3) including rectangular,
6 triangular, and hexagonal arrays. The embodiment
7 illustrated here is the hexagonal pattern wherein each well
8 is equidistant from the others. At the 45-foot spacing
9 illustrated here, each production well 2500 would serve an
10 area of 5260 square feet, for a field density of
11 approximately 8.3 producing wells to the acre. If there
12 were only one well 2500 under production, there would be six
13 heater wells 2501 and the ratio of heater wells to producer
14 wells 2500 would be six to one. However, in fields with
15 multiple production wells drilled on this hexagonal grid
16 pattern, the ratio of heater wells to production wells falls
17 as the number of wells increases. The heater to producer
18 ratio approaches 2 to 1 in large fields with more than a
19 thousand production wells.

20

21 FIG.28 shows the situation after the geothermic fuel
22 cell stacks in the heater wells 2501 have been operated for
23 a period of time. Concentric zones of progressively higher
24 temperature surround each of the heater wells 2501. The
25 zone closest to the heater well has increased in temperature

1 to match the operating temperature of the fuel cell modules,
2 750-1000°C. From that zone outward, the temperature of the
3 formation falls rapidly with radial distance from the heater
4 well. Here the 100°C. isotherm is shown to have progressed
5 more than half the distance to the next well.

6 The actual rates at which heat will move through a
7 given formation are influenced by a number of complex and
8 interactive variables, including: the formation's thermal
9 conductivity and heat capacity, the influence of migrating
10 fluids carrying heat and undergoing phase transitions,
11 potential endothermic reactions of various minerals, and a
12 number of other factors. However, a general idea of the
13 time necessary to sufficiently heat a block of resource is
14 known in the art to be around 10 years for heaters like the
15 GFCs embodied here, on 45 foot spacing in an oil shale
16 formation (see US Patent 4,886,118, Pg. 20, ¶ 2). This
17 figure can be reality tested by looking at the raw energy
18 required to heat one such resource block. If we take the
19 resource as oil shale and the thickness as 500 feet, the
20 total mass of the block served by a single production well
21 2500 will be roughly 350 million pounds. The specific heat
22 of oil shale varies with grade and other factors but can be
23 taken on average as around .3 BTU/lb./°F. Raising the
24 temperature of the block by an average 525°F., will require
25 on the order of 55.6 billion BTU. Thermal input to the

1 formation from the GFC heaters will be 750 BTU/ft/hr. One
2 third of the heat from each heater well 2501 is conducted
3 into the resource block, the other two thirds going to heat
4 other blocks. Therefore, each block receives an energy
5 input equivalent to the heat output of two heater wells.
6 Heat input to the block by two 500-foot long GFC heaters
7 will be 750,000 BTU/hr. To add the needed 55 billion BTU of
8 heat to the block at this rate will take around eight and a
9 half years. So we see good agreement between what is taught
10 in the art and what can be deduced as mathematically
11 feasible.

12 It is well known in the art that heating of underground
13 hydrocarbon formations like oil shales, tar sands, shut-in
14 oil fields, diatomites, etc. has several beneficial effects
15 which lead to increased production of oil and gas from those
16 formations. Heating the hydrocarbons above certain thermal
17 thresholds, 275-350°C. for oil shale, will cause those
18 hydrocarbons to liquefy and or volatilize. This causes both
19 a dramatic decrease in the hydrocarbon's viscosity and an
20 increase in pressure in the formation. According to US
21 Patent 4,886,118, sufficient pressure is created in oil
22 shale formations to create horizontal fractures through the
23 formation that establish communication between the heating
24 wells and the production well. The volatized gases and
25 reduced viscosity oils are driven under pressure away from

1 the heater wells 2501 and toward the production wells 2500.
2 There the products are removed to the surface. On the
3 surface the oil is shipped to market and some or all of the
4 gas stream is utilized to fuel the GFC heaters. (See
5 Fig. 26)

6

7 FIG. 29 shows an array of heater wells 2501 heating a
8 formation, and oil and gas being driven into collector wells
9 2500. In large fields, the proportion of heat lost to the
10 periphery can be relatively small and can be further reduced
11 if the field is expanded concentrically from the center out.

12

13 FIG. 30 shows an exploded perspective view of an
14 alternative embodiment of the interconnect plate. This
15 alternative plate 10200 is exemplary of the many alternative
16 configurations of the present invention that are
17 contemplated, including: multiple conduits of various
18 shapes, sizes, and configurations; multiple ceramic wafers
19 of various sizes and shapes in various configurations; and
20 other potential configurations which accomplish the same
21 function of heating resource formations with the heat
22 generated from fuel cells. It may be advantageous, for
23 example, to arrange the components of the fuel cells so the
24 heat producing ceramics and the hot exhaust gases are
25 located as closely as possible to the periphery of the cell.

1 This would give the heat produced by the cells a more direct
2 route of conduction into the resource formation.

3 Accordingly the ceramic wafer 1000 of the preferred
4 embodiment (see Fig. 1) has been fragmented into multiple
5 wafers 10000 , each of which sits at a separate location
6 around the perimeter of the plate 10200, in contact with the
7 networks of ridges 6161. In aggregate, the multiple wafers
8 might only produce the same amount of electricity and heat
9 and use the same amount of fuel as the single wafer 1000,
10 but multiple wafers 10000 so arranged might have advantages,
11 for example making the heat distribution around the heaters
12 more uniform. The same advantage may be gained by
13 positioning multiple exhaust conduits — 3999 for oxidant
14 exhaust and 2999 for fuel exhaust — around the periphery of
15 the plate 10200. Fuel passes through conduits 4999 and
16 oxidant through conduits 1999. These conduits, 1999, 2999,
17 3999, and 4999 are formed by stacking plates 10200 and
18 aligning holes 1111, 2222, 3333, and 4444, in the same
19 manner as in the preferred embodiment. The Figure shows the
20 cathode side of the plate 10200 which includes multiple
21 passages 6666, and 6060 for the movement of air (or other
22 oxidant) from the conduit 1999 to the ceramics 10000 and out
23 to the exhaust conduit 3999. Note that no bolt holes (5 in
24 the preferred embodiment, see Fig. 2A) are shown in plate
25 10200. This is because many other methods of achieving

1 suitable seals between plates in the fuel cell stacks are
2 contemplated, including: welding, brazing, various
3 adhesives, clamping, threading and other methods.

4

5 FIGS. 31 & 31A show one alternative embodiment of the
6 manifold 1555, of the many various embodiments contemplated.
7 The conduits of the manifold 9922, 9911, 9933, and 9944 in
8 this embodiment, and similar embodiments, are arranged
9 concentrically. This arrangement may be desirable in order
10 to increase the heat exchange efficiency of the manifold.
11 This arrangement of conduits increases the surface area
12 along which direct heat exchange can take place. Each of
13 the several process fluids travels in one of the conduits.
14 In the embodiment shown, hot fuel exhaust from the anode
15 will pass through the annular space 992, created between
16 conduits 9922 and 9911. This would have the advantage of
17 moving the hottest gases adjacent to the outermost surface
18 of the manifold, where their thermal energy can be most
19 readily conducted into the resource formation. The next
20 inner annular space 991, formed by conduits 9911 and 9933,
21 will carry the oxidant—usually air. The last annular space
22 993 will carry exhaust oxidant from the cathodes. This hot
23 exhaust will serve to pre-warm the incoming air traveling
24 through annular space 991, and the fuel traveling through
25 the cylindrical space 994 formed by conduit 9944. Other

1 potential arrangements of the conduits in the manifold are
2 possible and contemplated. For example, a greater
3 multiplicity of concentric conduits might be employed,
4 and/or the conduits might be subdivided into additional
5 conduits by the addition of partitions in longitudinal or
6 other orientations, etc.

7

8

9 FIGS. 32 & 32A show alternative embodiments of the
10 present invention. It is contemplated for example that the
11 system of making conduits by aligning holes in stacked
12 plates as in the preferred embodiment may be dispensed with
13 in favor of an arrangement of tubes or pipes 19991, 29991,
14 39991, 49991, 19992, 29992, 39992, and 49992 as conduits to
15 carry the necessary fluids to and from the fuel cells. Said
16 conduits could themselves be arranged variously with
17 alternative numbers and configurations of conduits serving
18 fuel cells of various types. For example, in addition to
19 rectangular-shaped planar cells 10300 (see Fig. 34), the
20 conduits might serve ring-shaped cells 10400 (see Fig. 35)
21 surrounding said conduits. It is contemplated that even the
22 planar type fuel cells, 400 (see Fig. 6), 10200 (see Fig.
23 29), 10300 (see Fig. 34), 10400 (see Fig. 35), or others,
24 might be eventually superceded by monolithic fuel cells of
25 various types (see U.S. Patent 5,770,326).

1

2 FIG. 33 shows a schematic diagram of the simplified
3 electrical circuit of a Geothermic Fuel Cell installation.
4 When supplied with fuel and oxidant, each fuel cell 400
5 generates an electric charge at a potential of .3 to 1 volt
6 per cell. All of the cells in a stack 600 are connected in
7 series. The cells are insulated from each other by the
8 gaskets and from the rest of the stack by nonconductive
9 elements or layers of insulation coating the casing and
10 compression bolts, etc. Electrons, liberated catalytically
11 from the fuel on the anode + side of each cell, are
12 conducted through the interconnect plate to the cathode -
13 side of the next cell. At the cathode, the electrons ionize
14 oxygen atoms in the air or other oxidant. The oxygen ions
15 are then conducted through the electrolyte to the anode side
16 of the next cell where the process is repeated. The
17 electrons follow this chain of conduction up the stack and
18 are removed through the conductor 160 in the manifold (see
19 Fig. 16). The stack is electrically isolated from the
20 ground by a layer of insulating grout (see Fig. 25). When
21 connected to a load 3300, through an external circuit 3333,
22 current will flow. For a typical GFC installation of the
23 exemplary type, cell potential would be .7 V/cell, with a
24 series pitch of 40 cells per foot of stack. For a stack
25 length of 100 feet, the series voltage would total 2800

1 volts. Each cell would produce 5 Watts of electric power,
2 giving the 100 foot stack a total power output of 20
3 kiloWatts. Current flow through this exemplary circuit would
4 then amount to just over 7 Amperes. Current flow would
5 continue around the circuit and return to the bottom,
6 Cathode, -, end of the stack via the current return cable
7 60 (see Fig. 22).

8

9 FIG. 34 shows an exploded perspective view of an
10 alternative embodiment of a Geothermic Fuel Cell. Here the
11 interconnect plate 10300 is fed with fluids passing through
12 individual conduits 19991, 29991, 39991, and 49991. The
13 cathode side of the interconnect plate 10300 is shown
14 connected to the air conduit 19991 by the etched air passage
15 66661. Oxidant exits conduit 19991 via a perforation 22221
16 aligned with passage 66661 and passes through said passage
17 and into the network of air supply channels 60601. The
18 cathode side of the rectangular electrode wafer 10001 sits
19 in contact with ridges 61611. Assembly of a stack of this
20 alternative configuration is accomplished through the
21 addition of gaskets and subsequent plates in a manner
22 similar to that used in the preferred embodiment.

23

24 FIG. 35 shows an exploded perspective view of another
25 alternative embodiment of a Geothermic Fuel Cell. Here the

1 interconnect plate 10400 is a circular ring, surrounding the
2 individual fluid conduits 19992, 29992, 39992, and 49992.
3 The cathode side of the interconnect plate 10400 is shown.
4 Oxidant from the surface passes through conduit 19992, and
5 exits the conduit via a perforation 22222; the oxidant then
6 passes through passage 66662 and enters the air channels
7 60602, where the oxidant gas follows a circuitous route
8 while in contact with the ring-shaped electrode wafer 10002.
9 The wafer ring 10002 sits in contact with the ridges 61612.
10 Construction of a stack of this configuration is
11 accomplished by means similar to those used in the preferred
12 embodiment.